RESTRICTED CIRCULATION

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METEOROLOGICAL OFFICE
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AGRICULTURAL MEMORANDUM NO 847

THE REDUCTION OF DIFFUSED LIGHT BY A SHELTER BELT OR SCREEN

1. INTRODUCTION

On average about half the total light received on a horizontal surface is in the direct solar beam and the remainder comes from the sky as a whole. If a shelter screen is erected to protect crops from wind it must reduce diffuse light and may also reduce direct light.

The formula for the length of the shadow cast by a long shelter screen has been given by Caborn (1965) and is reproduced without proof.

$$L = h \sin(180 - \beta + \gamma) \cdot \cot\alpha$$

Where L = length of shadow;
h = height of screen;
α = altitude of sun;
β = azimuth of sun;)
γ = direction of shelter screen) measured clockwise from North

The calculation of the reduction of diffuse light by a shelter screen is a little more difficult, but if it is assumed that the luminance of the sky viewed from a point on the earth's surface is uniform a formula can be derived.

2. THE DIFFUSE LIGHT RECEIVED ON A HORIZONTAL SURFACE FROM A UNIFORM SKY

Assume that the sky may be represented by a hemisphere of radius R centred at the point at which we wish to calculate the loss of light (O). Figure I shows the shelter screen viewed from O. The area of the projection of the small element of the belt EE^1FF^1 on to the hemisphere is:-

$$R^2 \cos\phi \, d\phi \, d\theta \qquad -(1)$$

Where θ is the azimuth angle measured from the line OB and ϕ is the angle of elevation. The solid angle subtended by this element is therefore $\cos\phi \, d\phi \, d\theta$. If the radiation received from unit solid angle of sky is I the radiation on a horizontal surface at O that is cut off by the element of screen EE^1FF^1 is:-

$$I \cos\phi \sin\phi \, d\phi \, d\theta \qquad -(2)$$

If equation 2 is integrated over the hemisphere it gives the total diffuse radiation on a horizontal surface from an unobstructed sky.

$$I_{TOTAL} = 4\int_{\theta=0}^{\pi/2}\int_{\phi=0}^{\pi/2} I \cos\phi \sin\phi \, d\phi \, d\theta = 2I\int_0^{\pi/2}\left[-\frac{\cos 2\phi}{2}\right]_0^{\pi/2} d\theta = 2I\int_0^{\pi/2} d\theta = I\pi \quad \ldots(3)$$

FH2B

The radiation cut off by the screen is:-

$$I_{LOSS} = \int_{\theta=\theta_1}^{\theta_2} \int_{\phi=0}^{\alpha} I \, Cos\phi \, Sin\phi \, d\phi \, d\theta \quad - - - - (4)$$

Where α is the angle of elevation subtended by the top of the shelter screen ie

$$Tan\alpha = \frac{h \, Cos\theta}{d}$$

Where h is the height of the screen and d is the perpendicular distance from O to the screen.

From 4

$$I_{LOSS} = \frac{I}{4} \int_{\theta=\theta_1}^{\theta_2} (1 - Cos 2\alpha) \, d\theta \qquad (6)$$

But $Tan\alpha = \frac{h}{d} Cos\theta = a \, Cos\theta$ say $\therefore Cos\alpha = \frac{1}{\sqrt{1+a^2 Cos^2\theta}}$

Thus

$$I_{LOSS} = \frac{I}{2} \int_{\theta_1}^{\theta_2} \left(1 - \frac{1}{1+a^2 Cos^2\theta}\right) d\theta = \frac{I}{2} \left[\theta - \frac{1}{\sqrt{1+a^2}} Tan^{-1}\left(\frac{Tan\theta}{\sqrt{1+a^2}}\right)\right]_{\theta_1}^{\theta_2} \quad - (7)$$

The percentage loss of diffuse light due to shelter screen is therefore:-

$$\frac{100 \, I_{LOSS}}{I_{TOTAL}} = \frac{100}{2\pi} \left\{ \theta_2 - \theta_1 - \frac{1}{\sqrt{1+a^2}} \left[Tan^{-1}\left(\frac{Tan\theta_2}{\sqrt{1+a^2}}\right) - Tan^{-1}\left(\frac{Tan\theta_1}{\sqrt{1+a^2}}\right) \right] \right\} - (8)$$

If the screen is infinitely long $\theta_2 = \frac{\pi}{2}$ and $\theta_1 = -\frac{\pi}{2}$, then

$$\frac{100 \, I_{LOSS}}{I_{TOTAL}} = \frac{100}{2\pi} \left\{ \pi - \frac{\pi}{\sqrt{1+a^2}} \right\} = 50 \left(1 - \frac{1}{\sqrt{1+a^2}}\right)$$

$$= 50 \left(1 - \frac{1}{\sqrt{1+h^2/d^2}}\right) \quad - - - - - - - - (9)$$

3. COMPARISON WITH OTHER ESTIMATES OF LOSS OF DIFFUSE LIGHT

A diagram showing loss of diffuse light appears in a leaflet "Shelter for Glasshouses" that was produced at the Bristol Meteorological Office in January 1975 and has been widely distributed. The same diagram appears in "Windbreaks" a booklet produced by ADAS in Kent. The diagram is reproduced as Appendix I to this note. It states on the diagram that each of the shelter belts shown causes a loss of about $1\frac{1}{2}\%$ of the diffuse light 3 ft above the ground at the middle of a $\frac{1}{2}$ acre block.

From the diagram the distance from the centre of the block to a shelter belt is 120 + 74 ft. The height of the shelter belt above the point of interest is 15 - 3 = 12 ft. One belt subtends an azimuth angle of 90 degrees. Therefore in the notation of equation 8. $a = 12/194 = 6.1856 \times 10^{-2}$, $\theta_1 = -\pi/4$ and $\theta_2 = \pi/4$ The percentage loss of light from equation 8 is:-

$$\frac{100}{2\pi}\left\{\frac{\pi}{4} + \frac{\pi}{4} - \frac{1}{\sqrt{1+3.8261\times10^{-3}}}\left[2\,\mathrm{Tan}^{-1}\left(\frac{1}{\sqrt{1+3.8261\times10^{-3}}}\right)\right]\right\} = 0.078\%$$

L G Morris (1965) gave an approximation to the percentage loss of light due to long opaque non-reflecting screen as

$$25\left(\frac{h}{d}\right)^2 = 0.096\% \quad \text{when } \frac{h}{d} = \frac{12}{194}$$

Morris's 1965 approximation is clearly not satifactory for a point very close to a shelter screen ($d \to 0$) and he has since, in an unpublished letter, produced an approximation which produces values very close to those given by equation 8 for finite shelter screens and reduces to equation 9 for an infinite screen.

The loss of light calculated from equation 9 when a = 12/194 is 0.095%.

4. CONCLUSIONS

Some Meteorological Office and ADAS leaflets have promulgated very pessimistic estimates of the loss of diffuse light due to shelter screens.

If diffuse light is assumed to be independent of direction a precise formula for the loss of light due to an opaque, non-reflecting screen may be obtained (equation 8) but since those conditions will not normally prevail in practice the simpler formula for an infinitely long screen, modified to allow for light transmission is recommended for practical use. Namely

$$\text{Percentage loss of diffuse light} = 50\,(1 - p)\left(1 - \frac{1}{\sqrt{1+a^2}}\right)$$

Where p = fractional permeability of screen for light (If the screen reflects light p must be adjusted to allow for that)

a = h/d

h = height of a long straight screed

d = distance from the screen to the point at which the light loss is required

It is noteworthy that in the worst case, when p = 0, the light loss is less than 1% for any point more than 5 screen heights away from the screen.

5. ACKNOWLEDGEMENTS

The author would like to thank Mr A J Dyke for pointing out the discrepancy between the leaflet "Shelter for Glasshouses" and the paper by L G Morris (1965). I would also like to thank Mr Morris for a very helpful letter on the subject.

REFERENCES

Morris L G — Glasshouse Heating and Ventilation in Relation to Wind and Shelter. Scientific Horticulture Vol XVII pp 47-52.

Caborn J M — Shelterbelts and Windbreaks (1965). Faber & Faber Ltd, London.

Any comments or suggestions on this paper should be referred to the author.

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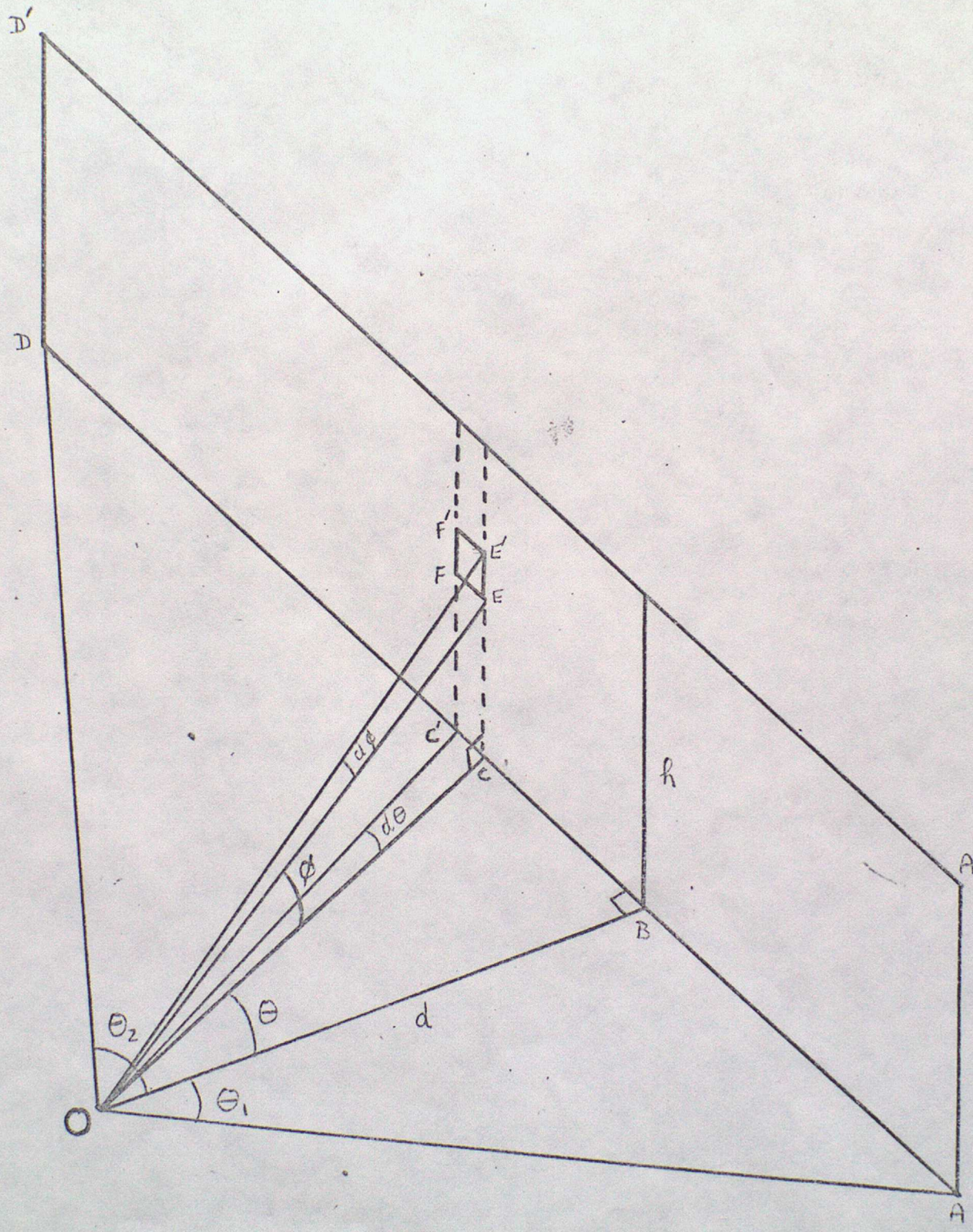
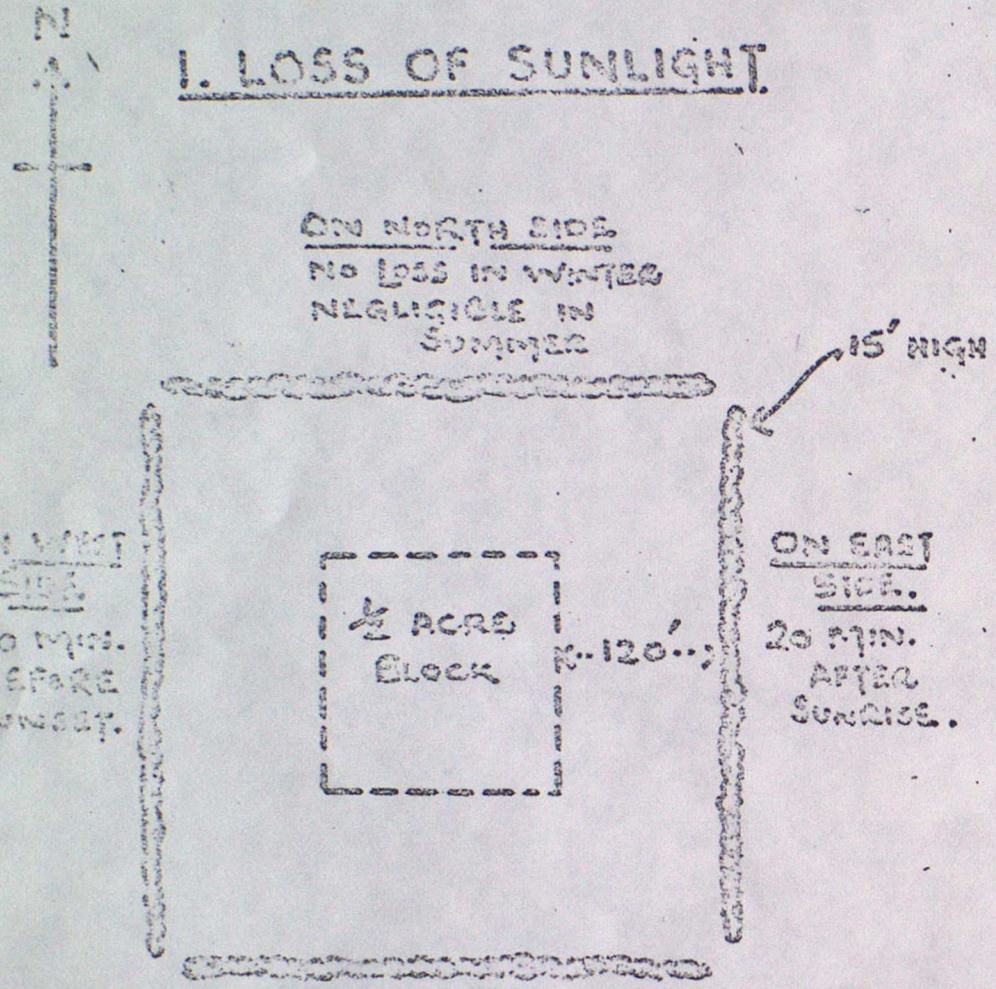
Figure 1

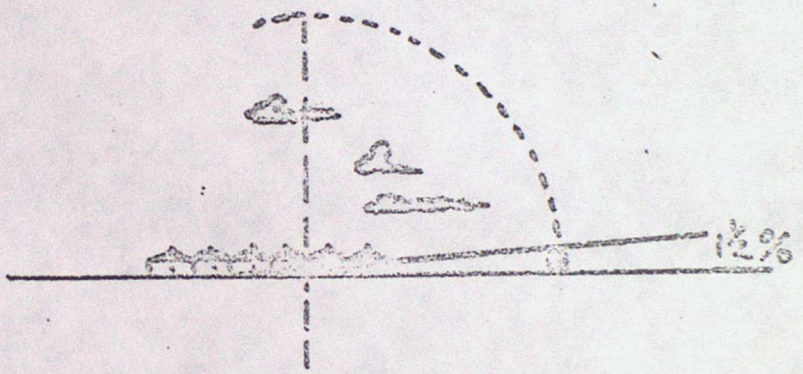


LOSS OF LIGHT DUE TO SHELTER BELTS.

1. LOSS OF SUNLIGHT.



2. LOSS OF DIFFUSE LIGHT.



Loss is about 1½% for each of the belts shown opposite.

[ESTIMATES 3' ABOVE GROUND AT MIDDLE OF ½ ACRE BLOCK]